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Experimental Investigation on Changes of Water Surface Profile with Gaussian Shaped Bottom and Side Roughness

Md. Rafiue Islam[a], Shariful Islam[b*], Md. Abdul Qaiyum Talukder[c], S. M. Rezwan Hossain[d]

***Abstract*— Bed roughness is a main factor on which the water surface profile depends. In this study the water surface profile over Gaussian shaped rough surface is experimentally investigated. The Gaussian shaped bed roughnesses were made of wood of different heights (2cm, 4cm and 6cm) with same base width of 12cm. Besides, these experiments were performed for same slope and varying Fraud number in the laboratory tilting flume. The multipurpose tilting flume is an artificial channel having a channel width of 8cm. Its maximum upstream water depth is 25cm. Discharge throughout the channel can be changed by rotating the key-wheel attached to the pump. Discharge throughout the channel varies from (0.0015-0.0043) m3/s. Its slope can also be changed by rotating the wheel at upstream of the channel. The pattern of water surface fluctuation over single Gaussian shaped roughness was found different than that of double Gaussian shaped roughness. For the same slope and same roughness, if the Fraud number is increased the maximum fluctuation was found to be increased. It is always found that the water depths at the upstream of roughness were constant which are gradually decreasing from the middle of roughness and at the downstream of roughness the water depth is the lowest.**

***Index Terms*— Bed roughness, Water surface profile, Fraud number, Gaussian shaped roughness, Water depth fluctuation.**

I. Introduction

The interruption problem between the boundary and the water surface profile of open channel flow such as the

***Md. Rafiue Islam[a]**, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, +8801673922867, (E-mail: rafiue.anik30@gmail.com).*

***Shariful Islam[b*]**, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, +8801710392954,*

(E-mail: bappytalukder@gmail.com).

***Md. Abdul Qaiyum Talukder[c]**, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, +8801710567200, (E-mail: qaiyumkuet@gmail.com).*

***S. M. Rezwan Hossain[d]**, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, +8801676772206, (E-mail: smrh.rezwan@gmail.com).*

formation of sand waves in river and seas are still one of the most interesting subjects. The water surface profile mainly depends on the bed surface and bed roughness of the channel. Nabi (2008) reported that the water levels during river floods, and hence the risk of flooding, depend on the hydraulic roughness of the river. Based on the flow parameter, different types of bed forms are observed in the river bed. One of the examples of this type of periodic irregularities on the river bed is "dunes". The development of dunes and the associated hydraulic roughness during a flood is complex. Initially dunes grow higher and make the river bed rougher, but in later stages the dunes grow longer with the opposite effect of making the river bed smoother. Fig. 1 shows the water surface profile over wavy bed surface.

Nabi, A. M. (2008) studied 3D Model of Detailed Hydrodynamics with Sediment Transport for Simulation of Subaqueous Dunes. The model aims at giving better insight into the development of the hydraulic roughness, and hence the flooding risk, during river floods. The good understanding thus obtained will allow the development of parameterized models for large spatial and temporal scales that can be used in operational model for flood early warning system the determination of design water levels.

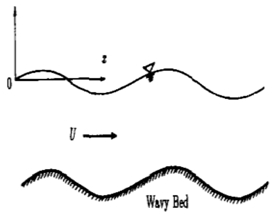

Fig. 1 Wavy bed surface

Erpicum S. (2006) studied the comparison of 2D turbulence models for steady flow computation in a macro-rough channel. In this study, experimental researches have been carried out at the laboratory of hydraulic construction (LCH-EPL) to assess the head losses generated by a succession of regular cavities at both bank of a straight channel. In this scope, numerical modeling of the experimental tests has been realized at the hydrology, applied hydrodynamics and hydraulic constructions research unit (HACH-ULg) with a 2D finite volume multiblock free surface flow solver.

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Ahmed, T. (2011) studied the experimental Investigation on Changes of Water Surface Profile with Bottom Roughness for different slope, velocity and discharges in the laboratory tilting flume. In this study he found,

I. For single roughness, the water surface was found to be abruptly falling down near the peak of the roughness and the water depth was found to be lowest just before the second trough.

II. For double triangular roughness, the water depth is the lowest just before the crest of the triangular roughness and the water surface is peak at the end of the roughness. The pattern of water surface fluctuation over single triangular roughness was found different than that of double triangular roughness.

III. If the fraud number is increase the maximum fluctuation was found to be increased.

IV. For the series of triangular roughness (11 triangles), the pattern of wavy surface profile was found to be varied with flow condition.

To study the fluctuation of water surface profile with single and double Gaussian Shaped roughness on channel bed and side wall for different flow condition and finally to find out how the water surface profile changes in the crest and near the trough of roughness if the bed surface is wavy or highly rough, is the main focus of this study.

II. METHODOLOGY

The tests were done in the laboratory multipurpose tilting flume, changing the following parameters.

- Size of roughness
- Discharges

The multipurpose tilting flume is an artificial channel having a channel width of 8cm. Its maximum upstream water depth is 25cm. Discharge throughout the channel can be changed by rotating the key-wheel attached to the pump. Discharge throughout the channel varies from (0.0015-0.0043) m3/s. Its slope can also be changed by rotating the wheel at upstream of the channel.

In this project the data of water depths was measured from the crest of roughness up to 40cm right and 40cm left taking an interval of 1cm. Fig. 2 shows the pictorial view of Gaussian shaped roughness of 2cm, 4cm, 6cm height which is made by wood.

Fig. 2 Gaussian roughness of different height

Weir tail gates are made by wood which were inserted at the downstream of the channel to control the depth of the flow. Fig. 3 shows the pictorial view of laboratory tilting flume in which experiments were performed to determine the water surface profile.

Fig. 3 Pictorial view of laboratory tilting flume

Table 1 shows the dimensions of the different types of Gaussian shaped roughness.

Table 1
Dimensions of the different types of Gaussian shaped roughness

Series No.	Height of the roughness Z_o(cm)	Base length of roughness L_o(cm)	Length of the full roughness L_R(cm)
1(Gaussian	2	12	12
2	2	12	24
3(	4	12	12
4	4	12	24
5(	6	12	12
6	6	12	24

III. RESULTS AND DISCUSSIONS

For the different heights and base lengths of the Gaussian shaped roughness, experimental investigations on the changes of water surface profile in an open rectangular channel were performed. Now results are presented for different cases and discussions are made based on the comparison of the results.

The experimental conditions (flow and roughness) are given in Table 2. The results and discussion are given below case by case.

Base length of each roughness is 12cm and channel slope is 1/296.

S1, S6, S8 for Single Gaussian Shaped Roughness

S2, S3, S4, S5, S7 and S9 for Double Gaussian Shaped Roughness.

Table 2
Different Test Cases

Series	Cases	Height of roughness Z_o(cm)	Length of the full roughness L_R(cm)	Discharge Q (m^3/s)	u/s depth mm, bottom	d/s depth mm side	d/s depth mm side	Velocity V (m/s)	Fraud no.
S1	S1	6	12	0.0033	141.5	101	110	0.29	0.25
S2	S2	6	24	0.0015	114	86	91	0.17	0.16
S3	S3	6	24	0.0019	123	91	92	0.20	0.18
S4	S6	4	12	0.0033	116	85	83	0.36	0.34
S5	S7	4	24	0.0033	120	84	90	0.36	0.34
S6	S8	2	12	0.0033	94	72	71	0.44	0.46
S7	S9	2	24	0.0033	96	73	72	0.44	0.46

A. Flow profile for series S1 (Gaussian shaped roughness of 1 nos x 6cm x l2cm)

Fig. 4 shows the comparison of Water surface profile over a Gaussian and Triangular shaped roughness placed at channel bottom and channel sidewall. It is found that the water depths at upstream for all the cases are constant that are gradually decreasing from the middle of roughness. At the downstream of the trough of roughness the water depth is the lowest.

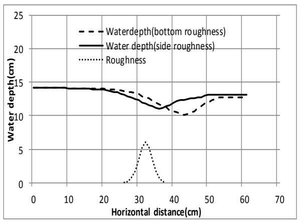

Fig. 4 Water surface profile over a Gaussian shaped roughness (Case S1C1)

The water depth is increasing gradually towards downstream. The water level fluctuation for single Gaussian shaped roughness is found 4.05cm when it is placed at bottom and 3.15cm when it is placed at side wall. Similarly for triangular roughness, it is found 3.5cm for bottom and 3.1cm for sidewall. It is also found that the lowest point of water depth for Gaussian shaped roughness is formed earlier than the Triangular roughness.

B. Flow profile for series S2 (Gaussian shaped roughness of 2 nos x 6cm x l2cm)

Fig. 5 shows the water surface profile over a Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found that the water depths at upstream for all the cases are constant that are starts to decrease gradually from the 1st roughness. The water depth is the lowest before the crest of 2nd roughness.

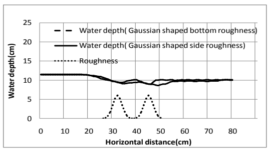

Fig. 5 Water surface profile over a Gaussian shaped roughness (Case S2C1)

Again the water surface is gradually increased and shows the peak at the end of roughness. Then it falls down towards the downstream next to 2nd roughness. Again it starts to increase gradually towards downstream. The water level fluctuation for double Gaussian shaped roughness is found 2.8cm, when it is placed at bottom and 2.3cm when it is placed at side wall. The positions of lowest points are formed very near to the trough of roughness.

C. Flow profile for series S3 (Gaussian shaped roughness of 2 nos x 6cm x l2cm)

Fig. 6 shows the water surface profile over a Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found that the water depths at upstream for all the cases are constant that are starts to decrease gradually from the 1st roughness. The water depth is the lowest before the crest of 2nd roughness. Again the water surface is gradually increased and shows the peak at the end of roughness. Then it falls down towards the downstream next to 2nd roughness. Again it starts to increase gradually towards downstream. The water level fluctuation for double Gaussian shaped roughness is found 3.2cm when it is placed at bottom and 3.1cm when it is placed at side wall. The positions of lowest points are formed very near to the trough of roughness.

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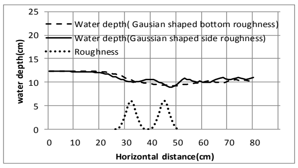

Fig. 6 Water surface profile over a Gaussian shaped roughness (Case S3C1)

D. Flow profile for series S4 (Gaussian shaped roughness of 1nos x 4cm x l2cm)

Fig. 7 shows the water surface profile over a Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found that the water depths at the upstream are constant those are gradually decreasing from the middle of roughness. At the downstream of the trough of roughness the water depth is the lowest. Then the water depth is increasing gradually towards downstream and flows at a constant water depth towards downstream. The water level fluctuation for single Gaussian shaped roughness is found 3.1cm, when it is placed at bottom and 3.3cm when it is placed at side wall. It is observed that the lower point of water depth is formed at a distance of 2cm downstream of trough for side roughness, it is found at a distance of 7cm downstream for the case of bottom roughness.

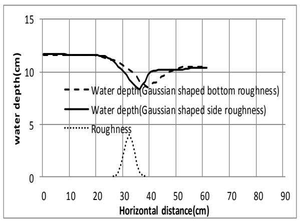

Fig. 7 Water surface profile over a Gaussian shaped roughness (Case S4C1)

E. Flow profile for series S5 (Gaussian shaped roughness of 2nos x 4cm x l2cm)

Fig. 8 shows the water surface profile over a Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found that the water level fluctuation for double Gaussian shaped roughness is found 3.6cm, when it is placed at bottom and 3.0cm when it is placed at side wall.

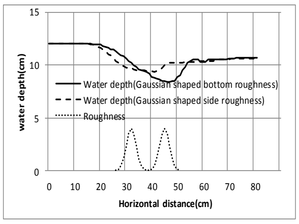

Fig. 8 Water surface profile over a Gaussian shaped roughness (Case S3C1)

F. Flow profile for series S6 (Gaussian shaped roughness of 1nos x 2cm x l2cm)

Fig. 9 shows the water surface profile over a single Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found that the water depths at the upstream of the roughness are constant which are gradually decreasing from the middle of roughness. At the downstream of the trough of roughness the water depth is the lowest. Then the water depth is increasing gradually towards downstream and flows at a constant water depth towards downstream. The water level fluctuation for single Gaussian shaped roughness is found 2.2cm, when it is placed at bottom and 2.3cm when it is placed at side wall. It is observed that the lower point of water depth is formed at a distance of 4cm downstream of trough for both the side & bottom roughness.

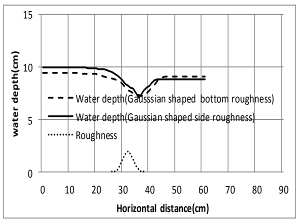

Fig. 9 Water surface profile over a Gaussian shaped roughness (Case S6C1)

G. Flow profile for series S7 (Gaussian shaped roughness of 2nos x 2cm x l2cm)

Fig. 10 shows the water surface profile over a double Gaussian shaped roughness placed at channel bottom and channel sidewall. It is found the water level fluctuation for single Gaussian shaped roughness is found 2.3cm, when it is placed at bottom and 2.4cm when it is placed at side wall.

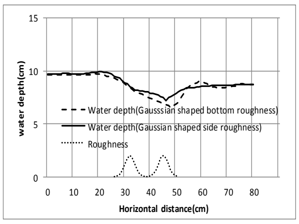

Fig. 10 Water surface profile over a Gaussian shaped roughness (Case S7C2)

Comparison of Maximum Fluctuation

In addition to experimental evaluation, analytical solution for lowering of water surface over a raised bottom is calculated analytically based on the specific energy equation using the concept of transition problem. The comparisons of experimentally and analytically computed values on water surface fluctuation are shown in Table 3. Table 3 shows the Water depth and maximum fluctuation of water surface for different cases.

Table 3
Water depth and maximum fluctuation of water surface for different cases

Cases	Size of the roughness	Fraud no.	Max. Fluct. (mm) Gaussian. bottom rough)	Max. Fluct. (mm) (Gaussian side rough)	Max. Fluct. (mm) Calc.
1.	1 nos×6×12	0.25	40.5	31.5	36.5
2.	2 nos×6×12	0.16	28	23	29
3.	2 nos×6×12	0.18	32	31	33.6
4.	1 nos×4×12	0.34	31	33	34
5.	2 nos×4×12	0.34	36	30	34
6.	1 nos×2×12	0.46	22	23	20
7.	2 nos×2×12	0.46	23	24	21

From the Table 3, it was found that the fluctuation of water depth is greater for cases (1-3) when the roughness placed at bottom compared to its placement at side. However, for cases (4-7) when the roughness height reduced the fluctuation for two placements does not vary. This is probably due to the boundary effect of sidewall. It is also found that, with increase in fraud number the fluctuation of water depth is increased. The measured fluctuation is found very near to calculated amount.

IV. Conclusion

From the above results and discussion it can be concluded that

- The fluctuation of water depth is greater for greater height of roughness and lower for smaller height of roughness.
- For roughness height of 6 cm, the fluctuation of water depth is found greater when the roughness placed at bottom compared to its placement at side. However, when the roughness height reduced the fluctuation for two placements does not vary. This is probably due to the boundary effect of sidewall.
- The measured fluctuation is found very near to calculated amount.
- With increase in fraud no. fluctuation of water depth is increased.

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Md. Rafiue Islam[a]

B. Sc. in Civil Engineering,

Khulna University of Engineering & Technology.

Shariful Islam[b*]

B. Sc. in Civil Engineering,

Khulna University of Engineering & Technology.

Md. Abdul Qaiyum Talukder[c]

B. Sc. in Civil Engineering,

Khulna University of Engineering & Technology.

S. M. Rezwan Hossain[d]

B. Sc. in Civil Engineering

Khulna University of Engineering & Technology